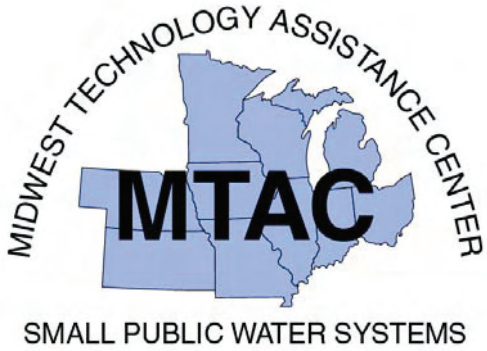


# Radium and Barium in the Ironton-Galesville Bedrock Aquifer in Northeastern Illinois

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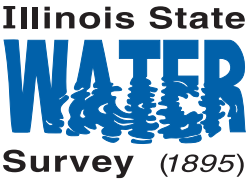
**Champaign, Illinois**



MTAC TR08-01
ISWS CR 2008-03

## Disclaimer

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# Radium and Barium in the Ironton-Galesville Bedrock Aquifer in Northeastern Illinois
Final Report

Walton R. Kelly

February 2008

Center for Groundwater Science
Illinois State Water Survey

*This report was printed on recycled and recyclable papers.*

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## Introduction

Elevated radium (Ra) and barium (Ba) concentrations are found in deep bedrock aquifers in parts of northern Illinois. There is rapid development occurring in the Chicago region, and many residents rely on groundwater for their drinking water. Radium and Ba contamination is the most important water quality issue for public water suppliers in most of northern Illinois. Water from deep bedrock aquifers typically has to be treated or blended to reduce concentrations of these contaminants. In addition to health considerations, the presence of Ba can cause precipitation of barite ($BaSO_4$) in well bores, pumps, and discharge pipes, necessitating expensive maintenance. Because most wells drilled into deep bedrock aquifers are open to multiple aquifers, allowing waters to mix within the borehole, it is difficult to establish if one or more specific aquifers are primarily responsible for the elevated Ra and/or Ba. Gilkeson et al. (1983) suggested that the Ironton-Galesville aquifer may be the major source of contamination, based primarily on indirect evidence.

The objective of this project was to identify and sample wells open only to individual deep bedrock aquifers in the Chicago region, and analyze for radioisotopes ($^{226}$Ra, $^{228}$Ra), Ba, and complete inorganic chemistry. A better understanding of the occurrence of Ra and Ba may help public water suppliers in siting future deep bedrock wells.

## Background

### Radium Radiochemistry

Radium has four radioisotopes, two of which are important in groundwater, $^{226}$Ra and $^{228}$Ra, with half-lives of 1600 years and 5.75 years, respectively. $^{226}$Ra and $^{228}$Ra are produced from two separate decay chains (Figure 1). Thorium (Th) is the immediate parent isotope for both $^{226}$Ra ($^{230}$Th) and $^{228}$Ra ($^{232}$Th). Stable isotopes of lead ($^{206}$Pb and $^{208}$Pb, respectively) are the eventual products of these decay chains.

The drinking water standard for total Ra is 5 picocuries per liter (pCi/L). The basis for the curie is the radioactivity of one gram of Ra. Radium decays at a rate of about 2.2 trillion disintegrations per minute (dpm), thus a picocurie represents 2.2 dpm. There is also a standard for gross alpha radiation (15 pCi/L). Gross alpha radiation includes all alpha-emitting radionuclides present in a sample, typically including uranium ($^{238}$U, $^{234}$U), $^{232}$Th, $^{230}$Th, $^{228}$Th, radon-222 ($^{222}$Rn), and $^{226}$Ra. Gross alpha analysis has primarily been used as a screening method to identify regions where high concentrations of radioactive elements occur in groundwater. Gross alpha is typically not a good proxy for $^{226}$Ra concentrations, however, because there is a poor correlation between the two, especially at high gross alpha concentrations.

### Radium and Barium in Groundwater

In order to have elevated levels of Ra in groundwater, a source is needed (i.e., U, Th) and mechanisms that would limit its solubility must not be significant. Uranium and Th may be present within mineral structures or adsorbed to mineral surfaces. Decay of U nuclides propels Th nuclides into solution. Thorium may, in turn, eject Ra into solution. Radium may also enter

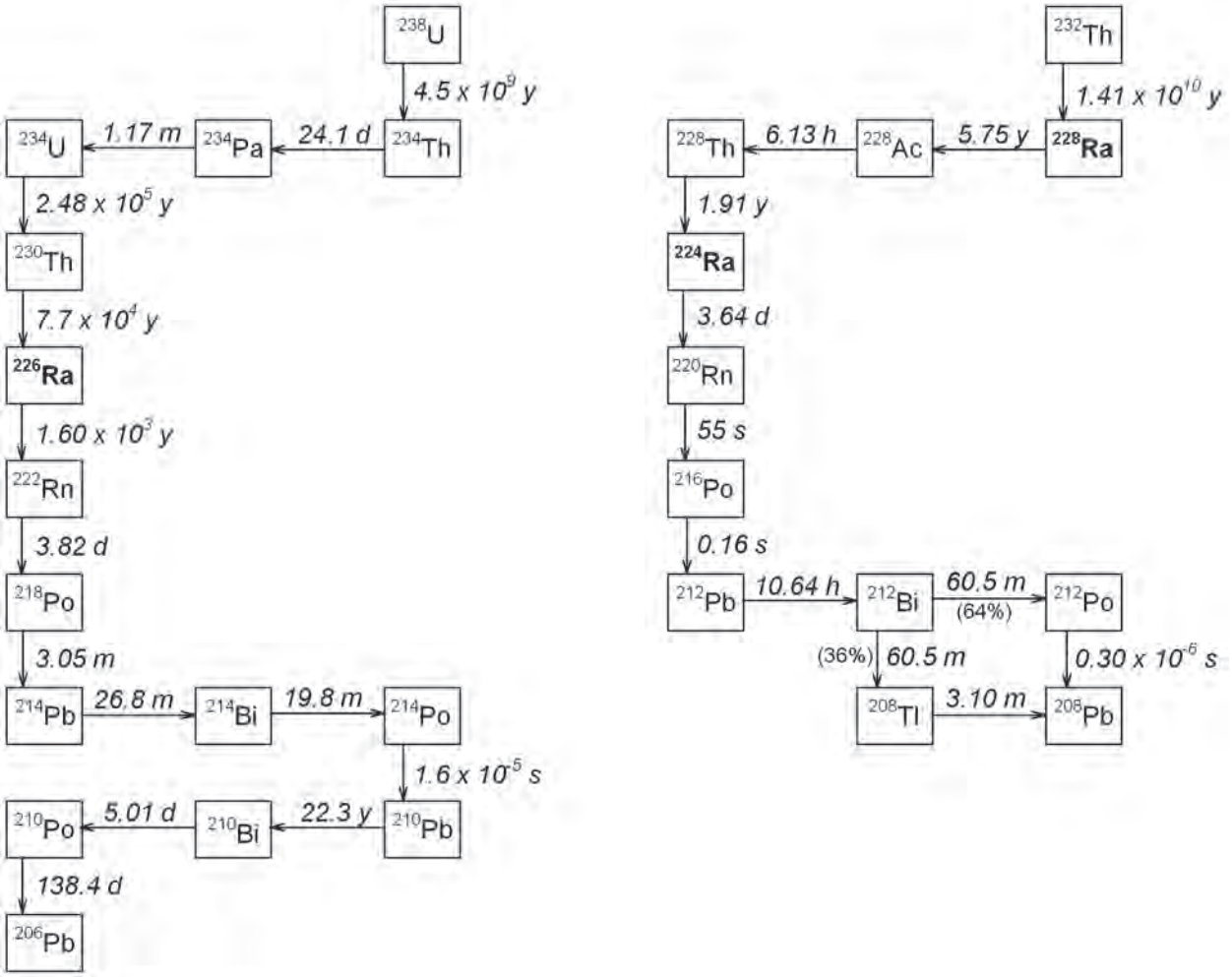


Figure 1. Decay chains that produce $^{226}$Ra and $^{228}$Ra.
Times are isotope half-lives (y = year; d =days; m = minutes).
Vertical direction represents alpha decay; horizontal direction represents beta decay.

solution via dissolution of minerals, desorption, or ion exchange (Krishnaswami et al., 1982; Dickson, 1990; Ku et al., 1992).

Thorium is highly insoluble, adsorbing strongly to negatively charged surfaces such as most silicate minerals (Stumm and Morgan, 1991; Langmuir and Herman, 1980). Decay of Th present on mineral surfaces can input significant amounts of Ra into solution (Davidson and Dickson, 1986; Krishnaswami et al., 1982). Disintegration reactions tend to weaken chemical bonds holding nuclides in the matrix, increasing the potential for leaching into solution (Fleischer, 1980). Mechanisms that remove Ra from solution include radioactive decay, adsorption or ion exchange, complexation with other adsorbed species, and coprecipitation in minerals as a trace constituent (Sturchio et al., 2001).

In relatively dilute groundwater, Ra is present primarily as uncomplexed $Ra^{2+}$. Aqueous complexes such as $RaSO_4$, $RaCO_3$, and $RaCl^+$ are only significant in brines with high concentrations of the respective anions. Organic complexation of Ra is not considered to be important.

Colloid and particulate transport may be important, but has not been widely documented. $^{226}Ra$ has been observed to be correlated with total dissolved solids (TDS), calcium (Ca), strontium (Sr), and Ba (Sturchio et al., 2001).

Since $^{228}Ra$ has a short half-life (5.75 years), it does not migrate significant distances from its source before decaying. Thus the distribution of $^{232}Th$ in source minerals is an important control on the concentration of $^{228}Ra$. $^{228}Ra$ concentrations are not correlated with TDS.

The $^{226}Ra/^{228}Ra$ ratio depends on the $^{238}U/^{232}Th$ ratio of the host rock, and thus provides information on the relative recoil rates of the two decay series. Recoil produces $^{226}Ra/^{228}Ra$ in groundwater up to 1.75 times that of the rock due to accumulation in the mobile pool of preceding nuclides in the decay chain (Davidson and Dickson, 1986). Assuming desorption rates are fast compared to Ra half lives, then $^{226}Ra/^{228}Ra$ ratios in groundwater and adsorbed to aquifer solids would be equal. Sturchio et al. (2001) found $^{226}Ra/^{228}Ra$ ratios in Paleozoic carbonate aquifers in Missouri, Kansas, and Oklahoma varied between 1.3 and 10, generally coinciding with the range in the aquifer rocks. Relatively elevated ratios of $^{226}Ra/^{228}Ra$ (> 5) are evidence of enrichment of the $^{226}Ra$ parent nuclides ($^{238}U$ and $^{234}U$) on the rock matrix relative to their normal abundance in rocks.

Equilibrium between dissolved Ra and a pure Ra mineral, such as $RaSO_4$, is precluded by the extreme insolubility of these minerals. For example, the solubility product of $RaSO_4$ is $10^{-4}$ (Kirby and Salutsky, 1964). Radium can, however, be precipitated in solid solution within Ca and Ba minerals. Barite ($BaSO_4$) is the mineral phase most effective at removing Ra from solution (Gordon and Rowley, 1957). Precipitation of gypsum ($CaSO_4 \cdot 2H_2O$) may also remove Ra from solution. Although precipitation of secondary barite may remove Ra (and Ba) from solution, subsequent barite dissolution due to changing geochemical conditions can, in turn, be a source of Ra (and Ba) to solution.

Adsorption exerts a strong control on Ra in dilute groundwater, dependant on substrate type, solution composition, and temperature. The potential for $^{226}Ra$ to desorb from surfaces is a function of the ionic strength of the water, increasing with increasing ionic strength. Thus higher $^{226}Ra$ concentrations are generally found in brines than in dilute water (Emrich and Lucas, 1963). Partitioning coefficients (i.e., retardation factors) for Ra have been reported to be in the range of $10^3$-$10^4$ for a variety of aquifer lithologies (Porcelli and Swarzenski, 2003). This suggests that under natural conditions, Ra will migrate at rates of $10^{-3}$-$10^{-4}$ times that of groundwater, and so is significantly retarded by adsorption.

The drinking water standard for Ba is 1 milligram per liter (mg/L). Sulfate is the most important control of Ba solubility due to barite precipitation; elevated Ba levels are usually only reported in water depleted in $SO_4^{2-}$ (Gilkeson et al., 1978; Marandi et al., 2004). Sulfate is typically lost in aquifers due to $SO_4^{2-}$ reduction, resulting in sulfide production and increased alkalinity (Gilkeson et al., 1981). Thus elevated Ba concentrations are usually found where conditions are strongly reducing.

## Radium and Barium in Illinois Groundwater

Deep bedrock aquifers in northern Illinois are shown in Figure 2. The principal aquifers from top to bottom layers in this interval are the Galena-Platteville (Ordovician age), Ancell (Ordovician), Ironton–Galesville (Cambrian), and Elmhurst–Mt. Simon (Cambrian). These aquifers are primarily sandstones and limestones. In northeastern Illinois, the Ancell and Ironton–Galesville aquifers, together with the intervening Prairie du Chien–Eminence–Potosi–Franconia confining unit, sometimes collectively are referred to as the deep bedrock aquifer

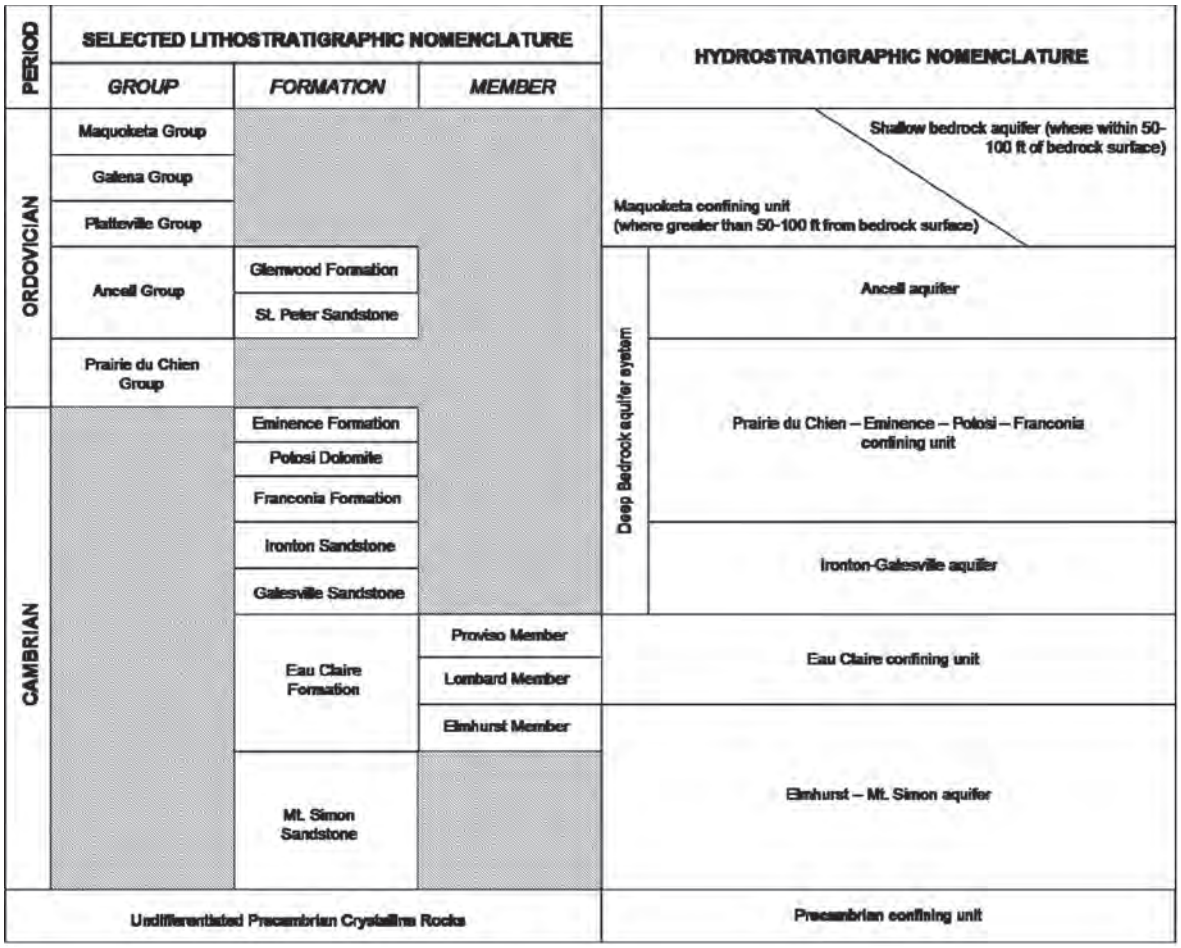


Figure 2. Hydrostratigraphic and selected lithostratigraphic nomenclature applied to Cambrian and Ordovician rocks in northeastern Illinois.

system because the entire interval is frequently used by water supply wells serving public water systems and self-supplied industries in the region. In such wells, the interval from the top of the Ancell aquifer to the base of the Ironton–Galesville aquifer is left open, or unlined, except where there needs to be casing to prevent caving of the Ancell aquifer. Some wells open to the deep bedrock aquifer system also are left open to overlying and underlying bedrock units, including the Galena-Platteville and/or the upper portion of the Elmhurst–Mt. Simon aquifer.

Elevation of the deep bedrock aquifers declines to the east-southeast across northeastern Illinois, so these bedrock units are buried at increasingly greater depths in that direction. This general structure is complicated by displacement of units along the Sandwich Fault Zone, a series of closely spaced, nearly vertical faults that extend eastward into northwestern Kendall County and into west-central Will County (Kolata et al., 1978). In extreme west-central Kendall County, on the upthrown, southern block of the Sandwich Fault Zone, the Prairie du Chien–Eminence–Potosi–Franconia confining unit immediately underlies (subcrops) the glacial drift, as does the Ancell aquifer in a belt of west-central to southwestern Kendall County. Pennsylvanian rocks

unconformably overlap the Cambrian and Ordovician rocks in southern Grundy County and extreme southwestern Will County. Because these Pennsylvanian rocks are relatively impermeable shale, their presence reduces groundwater circulation between the surface and the Ancell aquifer and underlying units.

High activities of $^{226}Ra$ in groundwater from Cambrian and Ordovician bedrock aquifers in northern Illinois have been reported since the 1950s (Stehney, 1955; Lucas and Ilcewicz, 1958, Krause, 1959; Emrich and Lucas, 1963; Holtzman, 1964). A map of Ra concentrations measured between 2002 and 2005 by the Illinois Environmental Protection Agency (IEPA) is shown in Figure 3. In the most comprehensive study of Ra in Illinois, Gilkeson et al. (1983) sampled approximately 90 wells from Cambrian-Ordovician bedrock aquifers in northern Illinois. They reported $^{226}Ra$ activities between 0.1 and 36.9 pCi/L, $^{228}Ra$ between 0.5 and 32.7 pCi/L, and total Ra ($^{226}Ra$ + $^{228}Ra$) between 2.3 and 50.2 pCi/L. There was no obvious correlation between the two isotopes, although samples with low activities of $^{226}Ra$ (< 5 pCi/L) generally also had activities of $^{228}Ra$ < 5 pCi/L. $^{226}Ra/^{228}Ra$ ratios varied between 0.2 and 13.1 (one anomalous value of 41.0), with most ratios between 1 and 5.

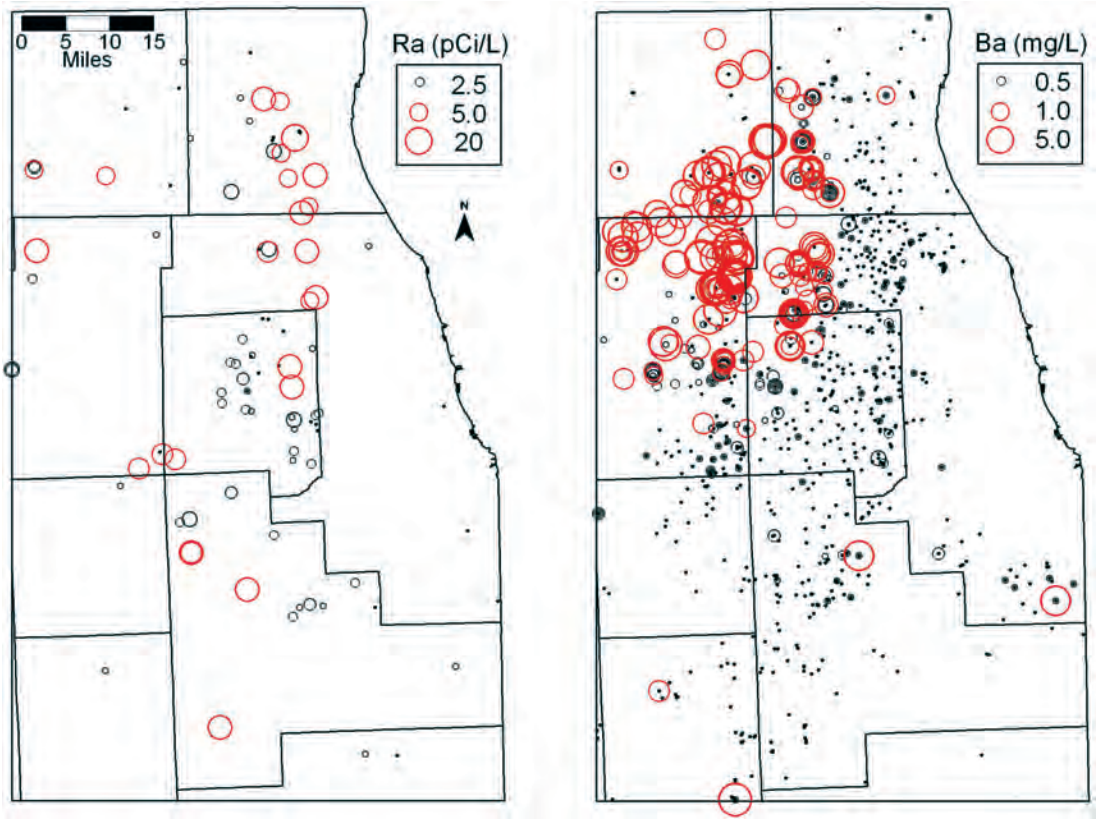


Figure 3. Ra and Ba concentrations in deep bedrock aquifers. Data from IEPA ambient water quality and ISWS groundwater quality databases. Size of symbol indicates concentrations. Red symbols indicate values greater than the MCL (5 pCi/L for Ra; 1 mg/L for Ba).

Regionally, the lowest Ra concentrations (almost always < 5 pCi/L) are in the zone of primary recharge to the deep bedrock aquifers (Boone and DeKalb Counties and counties west) where the confining Maquoketa Group is absent, the Ancell aquifer subcrops, and groundwater is relatively young (Figure 3). Concentrations generally increase hydrologically down-gradient. The highest Ra concentrations are found south of Chicago, where groundwater is highly mineralized. $^{226}Ra$ is the dominant isotope in these waters (Gilkeson et al., 1983).

Gilkeson et al. (1983) concluded that the high Ra concentrations were coming from sandstones, which are the primary water-producing strata; specifically, the Ironton-Galesville sandstone, inferred from results from a handful of wells open only or primarily to the Ironton-Galesville aquifer. It was difficult to pinpoint the exact formation(s) because most wells that they sampled were open to multiple aquifers.

Gilkeson et al. (1983) found a somewhat linear relationship between TDS and $^{226}Ra$. All of the samples with $^{226}Ra$ concentrations < 2.5 pCi/L had TDS concentrations < 600 mg/L, and all samples with TDS values > 1500 mg/L had $^{226}Ra$ concentrations > 6.0 pCi/L. However, TDS concentrations alone were not enough to explain $^{226}Ra$ concentrations, as many samples with relatively high $^{226}Ra$ concentrations had low TDS concentrations.

Radon ($^{222}Rn$), the daughter product of $^{226}Ra$, was detected in all samples (Gilkeson et al., 1983). This indicates that $^{226}Ra$ is ubiquitous on the matrix of the Cambrian-Ordovician aquifers, even where dissolved $^{226}Ra$ concentrations were low. They also concluded that barite was the major control on Ra solubility, as all samples were in equilibrium with barite.

When Grundl and Cape (2006) sampled Wisconsin bedrock aquifers that are basically the same as those in northern Illinois, they reported results similar to Gilkeson et al. (1983). They found that waters were saturated with respect to calcite ($CaCO_3$) and barite across their entire transect, with $SO_4^{2-}$ concentrations increasing from unconfined to confined conditions. They concluded that calcite was unlikely to be an important sink for Ra, and that barite, and not adsorption, was the important control. Also, barite must be finely dispersed throughout the aquifer. The Ra/Ba ratio increased as $SO_4^{2-}$ increased due to barite precipitation reducing the Ba concentration.

Barium concentrations greater than 5 mg/L are found in deep bedrock aquifers over large parts of McHenry and Kane Counties, northwestern Cook County, and southwestern Lake County (Figure 3). Concentrations are > 1 mg/L over most of McHenry and Kane counties, northeastern and central DeKalb County, western Lake County, and northwestern Cook and DuPage Counties, and exceeds 20 mg/L in a few wells (Gilkeson et al., 1983). Barium concentrations are elevated where $SO_4^{2-}$ is low (< 10 mg/L). Sulfate concentrations increase substantially to the east and southeast of this area, reaching levels as high as 800 mg/L.

Gilkeson et al. (1983) concluded that Ba concentrations were highest in the most productive Cambrian-Ordovician units, the St. Peter (Ancell) and Ironton-Galesville aquifers, especially the latter. Thus it would not be practical to seal off the offending units.

There are a number of documented pump failures due to barite precipitation. This is due to cross-formational flow in open boreholes due to head differences. The Ironton-Galesville has a lower head, thus water from overlying bedrock recharges to it when the pump is off. If the well is also open to the underlying Eau Claire and/or Mt. Simon units, groundwater flows up into the Ironton-Galesville aquifer.

## Methods

Wells for sampling were identified by searching the Illinois State Water Survey (ISWS) well database, which includes private, industrial, commercial, and public water well information. The database includes information on a well's open interval or screen location and contributing aquifer(s). The goal of this study was to identify wells open to only one of four deep bedrock aquifers in northern Illinois: (1) Galena-Platteville; (2) Ancell (St. Peter); (3) Ironton-Galesville; and (4) Mt. Simon. Aquifer identity was corroborated by comparing the depth range of the open interval with elevations of lithostratigraphic units in northeastern Illinois estimated from geological mapping in the region. A total of 25 wells in five geographic groups were selected for sampling (Table 1 and Figure 4). Groups were selected based on proximity of wells open to different aquifers. All groups were located in areas known to have Ra activities > 5 pCi/L; group 2 and part of group 6 were located in the region with Ba concentrations above the MCL.

**Table 1. Wells sampled in study.**

| *Group* | *County* | *Well Owner* | *Well #* | *ISWS p#* | *Depth (ft)* | *Aquifer* | *Lithology* | *Twn Rng Section* |
|---|---|---|---|---|---|---|---|---|
| 2 | Kane | Clesen Brothers | W | 404559 | 260 | G/P | Limestone | 41N 08E 35 |
| 2 | Kane | Clesen Brothers | N | 401971 | 375 | G/P | Limestone | 41N 08E 35 |
| 2 | Kane | Elgin CC | 5 | 411335 | 800 | Ancell | Not stated | 41N 08E 17 |
| 2 | Kane | City of Gilberts | 3 | 400071 | 1330 | I/G | Sandstone | 42N 07E 25 |
| 2 | Kane | City of Gilberts | 4 | 400070 | 1330 | I/G | Sandstone | 42N 07E 25 |
| 2 | Kane | Highlands of Elgin GC | 3 | 411556 | 902 | Ancell | LS/SS | 41N 08E 22 |
| 2 | Kane | City of South Elgin | 8 | 400064 | 1980 | Mt. Simon | Sandstone | 40N 08E 05 |
| 2 | Kane | City of South Elgin | 9 | 400065 | 1958 | Mt. Simon | Sandstone | 40N 08E 05 |
| 3 | Kane | Black Sheep GC | 1 | 412116 | 880 | Ancell | Sandstone | 39N 07E 28 |
| 3 | Kane | City of Montgomery | 14 | 411012 | 1403 | I/G | Sandstone | 38N 07E 35 |
| 3 | Kendall | City of Yorkville | 9 | 411221 | 1368 | I/G | Sandstone | 37N 07E 15 |
| 4 | Will | City of Channahon | 4 | 410382 | 1647 | I/G | Sandstone | 34N 09E 30 |
| 4 | Grundy | Exelon Fire Institute | 2 | 412026 | 1375 | I/G | Sandstone | 33N 07E 08 |
| 4 | Grundy | Reichhold Chemical | 1 | 401655 | 706 | Ancell | Sandstone | 34N 08E 34 |
| 4 | Grundy | Reichhold Chemical | 2 | 401657 | 710 | Ancell | Sandstone | 34N 08E 34 |
| 5 | Cook | Allstate | 5 | 400847 | 1352 | I/G | Sandstone | 42N 12E 19 |
| 5 | Cook | Allstate | 6 | 400848 | 1328 | I/G | Sandstone | 42N 12E 19 |
| 5 | Cook | Des Plaines MHP | 3 | 405051 | 960 | Ancell | LS/SS | 41N 11E 25 |
| 5 | Cook | Glen Club GC | 1 | 411269 | 1400 | Ancell | Sandstone | 42N 12E 27 |
| 5 | Cook | Touhy MHP | 6 | 405568 | 1295 | I/G | SS/LS | 41N 11E 25 |
| 5 | Cook | Wilmette GC | 4 | 404928 | 798 | G/P | Limestone | 42N 12E 25 |
| 6 | Lake | City of Lake Villa | 14 | 412143 | 1000 | Ancell | LS/SS | 45N 10E 05 |
| 6 | Lake | Scott Byron & Co. | 1 | 411365 | 1060 | G/P | LS/SS | 46N 11E 25 |
| 6 | Lake | Thunder Hawk GC | 1 | 405559 | 1305 | I/G | Sandstone | 46N 12E 29 |
| 6 | Lake | City of Volo | 5 | 412003 | 1400 | Mt. Simon | Sandstone | 44N 09E 02 |

CC = country club
GC = golf club
MHP = mobile home park
G/P = Galena/Platteville
I/G = Ironton/Galesville

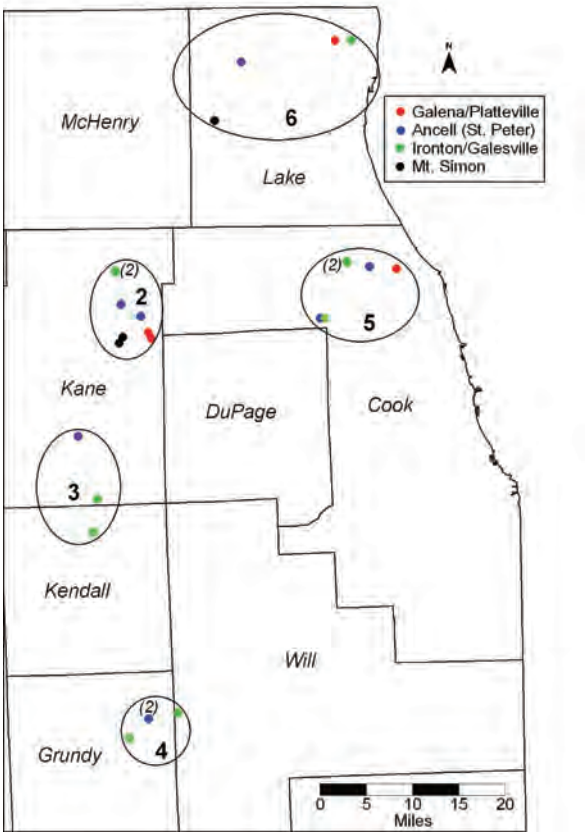


Figure 4. Sampled wells, identified by source aquifer and group.
*(2)* indicates 2 wells sampled at same location.

Wells were sampled between August 11 and August 31, 2007. Samples were collected as close to the wellhead as possible, prior to any treatment, using the well's down-hole pump. Field parameters (temperature, pH, specific conductance (SpC), oxidation-reduction potential (ORP), and dissolved oxygen) were monitored in a flow-through cell using a mini-sonde (Hydrolab® Series 5). All electrodes were calibrated at the beginning of each day of sample collection. Once all parameters had stabilized, water was passed through 0.45 µm filter capsules and acidified, if necessary (Table 2). Unfiltered samples for gas analysis were collected in pre-weighed Cubitainers®, to which a vacuum had been applied. Gas samples were not collected at several wells because it was impossible to collect samples that were not aerated. Hydrogen sulfide ($H_2S$) analysis was conducted in the field at the time of sample collection using a field colorimetric method (CheMetrics®). Sample containers were kept on ice in coolers until return to the ISWS, where they were refrigerated (4°C) until analysis.

At the end of a sampling day, all gas samples were processed. This consisted of weighing the sample, measuring water temperature, withdrawing the gas using a syringe and needle, measuring volume of gas, and injecting the gas into previously evacuated glass vials fitted with septa. Prior to extracting the gas, the needle and dead space at the end of the syringe was filled with a saturated $Na_2SO_4$ solution to minimize air contamination in the samples and help prevent dissolution of the gas sample into the solution while in the syringe. The quantity of water was

**Table 2. Sample collection information.**

| *Analyte* | *Container material* | *Sample size* | *Acid* |
|---|---|---|---|
| $^{226}$Ra, $^{228}$Ra | HDPE bottle | 2 L | 0.5% $HNO_3$ |
| Metals | HDPE bottle | 125 mL | 0.5% $HNO_3$ |
| Anions | HDPE bottle | 250 mL | None |
| $NH_3$-N | HDPE bottle | 125 mL | 0.2% $H_2SO_4$ |
| Alkalinity | HDPE bottle | 125 mL | None |
| DOC | Amber glass bottle | 250 mL | 0.5% $H_3PO_4$ |
| Gases | LDPE Cubitainer® | 1 gallon | None |

determined from the difference between the full and empty weights of the Cubitainers®. Gas samples were analyzed on a gas chromatograph. The amount of methane ($CH_4$) in water samples was determined by analyzing the composition of the gas extracted from the samples and using a best-fit polynomial for $CH_4$ solubility data between 0 to 30°C (Dean, 1992). Hackley (2002) describes this method in more detail.

Radium analyses were conducted at the Illinois Emergency Management Agency Nuclear Safety Laboratory in Springfield, Illinois. All other analyses except gases were conducted at the ISWS Public Service Laboratory (PSL) in Champaign, Illinois. Gases were analyzed at the Illinois State Geological Survey (ISGS) Isotope Laboratory in Champaign, Illinois.

$^{226}$Ra was measured by radon-emanation and alpha counting by scintillation counter (United States Environmental Protection Agency [USEPA] Method 903.1) and $^{228}$Ra using barium sulfate precipitation (USEPA Method Ra-05). Metals (except arsenic) were analyzed by coupled plasma optical emission spectrometry, anions by ion chromatography, and alkalinity by titration with 0.02 N $H_2SO_4$. Arsenic analyses were performed using graphite furnace atomic absorption. Ammonia and TKN analyses were performed using automated colorimetry. Dissolved organic carbon was measured using a Tekmar Dohrmann® carbon analyzer.

Thermodynamic geochemical calculations were conducted using The Geochemist's Workbench® computer program, release 4.0. Calculations included mineral saturation indices (SI) and TDS. Saturation indices measure the thermodynamic saturation state of a solution with respect to specific minerals. A value of 0 indicates a water sample saturated with that particular mineral, values > 0 indicate supersaturation (i.e., mineral would be expected to precipitate out of solution), and values < 0 indicate undersaturation (i.e., if the mineral is present, it would be expected to dissolve).

## Results

### Distribution of Radium and Barium

Radium activities greater than the maximum contaminant level (MCL) were found in all groups, while Ba concentrations greater than its MCL were found only in northeastern Kane County (group 2) and one well in western Lake County (group 6). These results are consistent with previous samplings. (Complete sample results are provided in the appendix. Total Ra ($^{226}$Ra + $^{228}$Ra) and Ba results are mapped in Figure 5.)

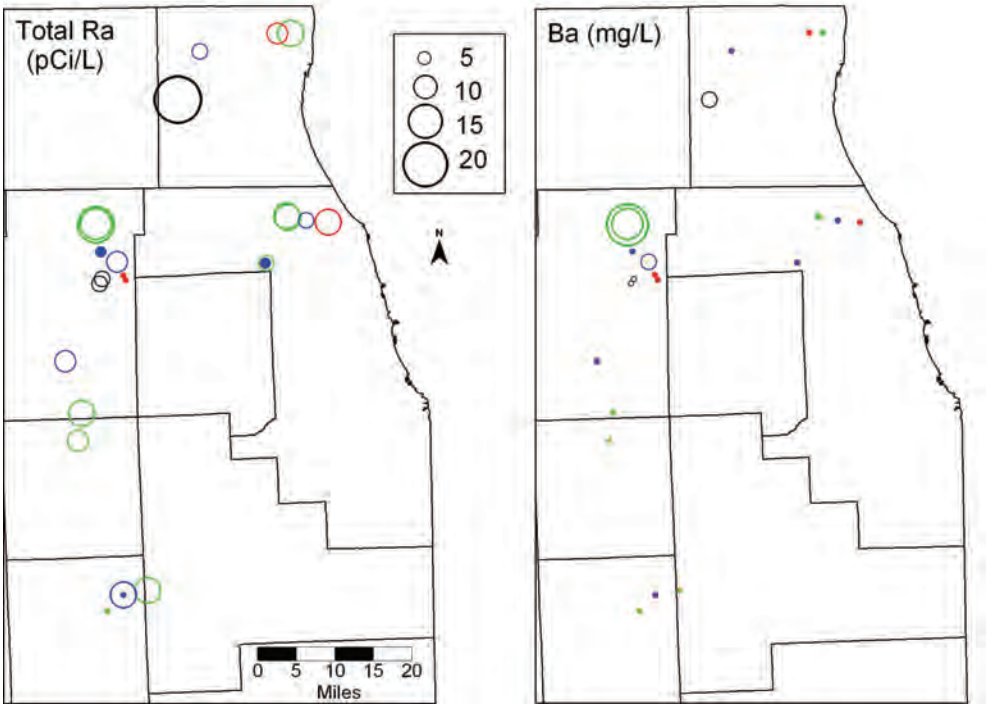


Figure 5. Total Ra ($^{226}$Ra + $^{228}$Ra) and Ba concentrations in sampled wells. Size of symbol indicates concentrations. Colors indicate aquifer: red = Galena/Platteville; blue = Ancell; green = Ironton/Galesville; black = Mt. Simon.

There were a few statistically significant differences for Ra based on source aquifer when considering the entire data set, although the differences are not visually obvious (Figure 6). There were no significant differences for $^{226}$Ra, but both the Ironton/Galesville and Mt. Simon wells had significantly greater $^{228}$Ra activities than either the Galena/Platteville or Galena wells (based on rank sum or t tests at 95 percent confidence level). Ironton/Galesville wells also had significantly higher total Ra activities than the Ancell wells. Differences among source aquifers are more visibly obvious within the geographic groups (Figure 7). In most groups, the highest Ra activities generally were from Ironton/Galesville wells, especially when compared to Ancell wells. The highest total Ra activity was found in a Mt. Simon well in group 6 (Volo 5), although two other Mt. Simon wells sampled did not have particularly high Ra levels.

The highest Ba concentrations (18.1 and 14.7 mg/L) were found in the two Ironton/Galesville wells in group 2 (Gilberts 3 and 4). The other two wells with Ba in excess of 0.5 mg/L were an Ancell well (Highlands of Elgin Golf Course; 5.8 mg/L) and Mt. Simon well (Volo 5; 5.7 mg/L). There were not enough samples to determine if the Ironton/Galesville aquifer has significantly higher Ba concentrations in this region.

## Radium Isotopes

$^{226}$Ra was detected in all samples and $^{228}$Ra was detected in all but four samples (> 1.0 pCi/L). A plot of $^{228}$Ra versus $^{226}$Ra indicates that $^{228}$Ra was the primary source of radioactivity in all the Mt. Simon wells and most of the Ironton/Galesville wells (Figure 8). In contrast,

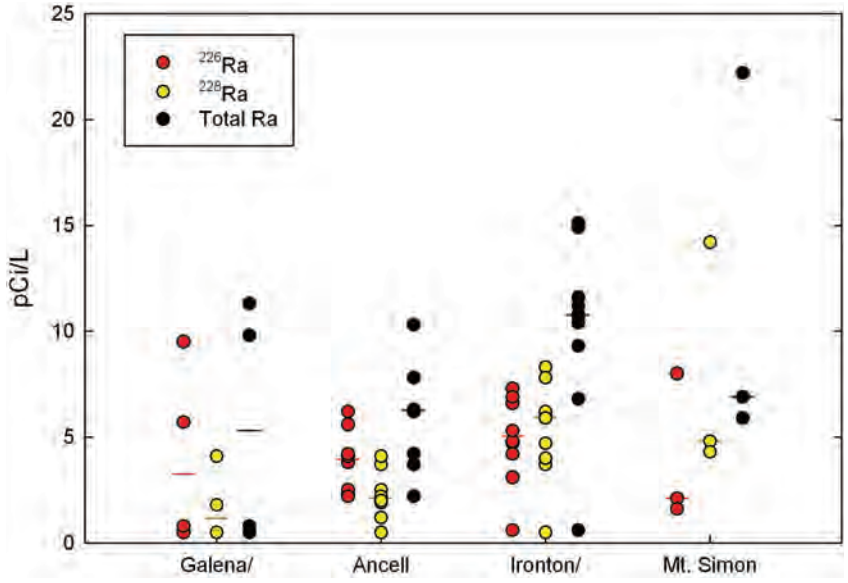


Figure 6. $^{226}$Ra, $^{228}$Ra, and total Ra ($^{226}$Ra + $^{228}$Ra) activities as a function of source aquifer. Horizontal marks indicate median values.

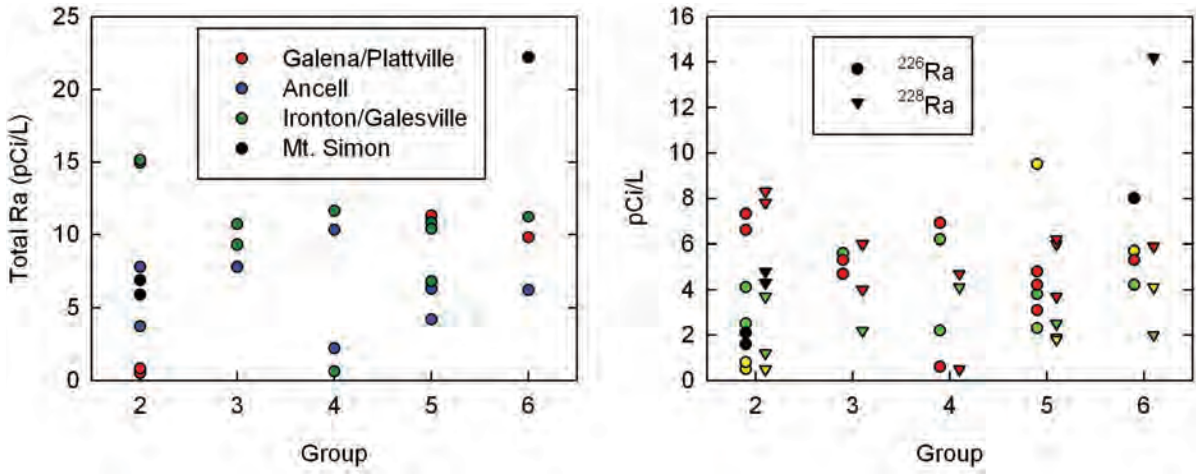


Figure 7. Total Ra ($^{226}$Ra + $^{228}$Ra), $^{226}$Ra, and $^{228}$Ra activities as a function of sample group and source aquifer.

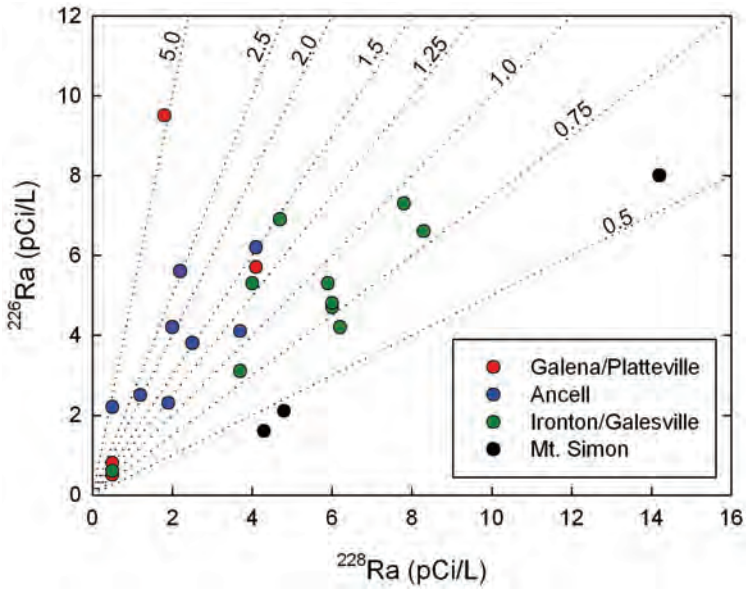


Figure 8. $^{226}Ra$ vs. $^{228}Ra$ as a function of source aquifer. Dotted lines represent different $^{226}Ra/^{228}Ra$ ratios.

$^{226}Ra$ was the primary source of radioactivity in all the Ancell and Galena/Platteville wells. (In two of the Galena/Platteville wells, $^{228}Ra$ was below detection (< 1.0 pCi/L) while $^{226}Ra$ was detectable, but at levels < 1.0 pCi/L.)

To convert radioactivity to concentration, the number of atoms (N) is first determined using the following equation:

$$N = A / (0.693T_{1/2}) \quad (1)$$

A is the measured radioactivity in dpm and $T_{1/2}$ is the isotope half-life (1600 years for $^{226}Ra$, 5.75 years for $^{228}Ra$). N is related to the mass (m) of the radionuclide through Avogadro's constant ($A_o$ = 6.022 x $10^{23}$ atoms/g atomic wt) and the radionuclide's gram-atomic weight ($G_a$):

$$m = (N/A_o)(G_a) \quad (2)$$

Concentrations of $^{226}Ra$ and $^{228}Ra$ calculated from pCi/L are reported in Table 3. $^{226}Ra$ concentrations were 100 to 1000 times greater than $^{228}Ra$.

## Geochemistry

The major ion data were plotted on a piper diagram (Figure 9). No consistencies were apparent based on source aquifer, but there did appear to be differences based on geographic group. The four wells in group 4 had relatively higher proportions of chloride ($Cl^-$), sodium (Na), and potassium (K) than the other groups. These wells are located in northeastern Grundy and southwestern Will Counties, and lie south of the Sandwich fault zone that runs through Kendall and Will Counties. Two Ancell wells in group 4 (Reichhold Chemical 1 and 2) were shallower

**Table 3. Ra activities and concentrations and Ba concentrations.**

| *Group* | *Well Owner* | *Well #* | *Aquifer* | *$^{226}$Ra pCi/L* | *$^{228}$Ra pCi/L* | *Ba mg/L* | *$^{226}$Ra ng/L* | *$^{228}$Ra ng/L* |
|---|---|---|---|---|---|---|---|---|
| 2 | Clesen Brothers | W | G/P | 0.5 | <1.0 | 0.066 | 0.51 | <0.00367 |
| 2 | Clesen Brothers | N | G/P | 0.8 | <1.0 | 0.078 | 0.81 | <0.00367 |
| 2 | Elgin CC | 5 | Ancell | 2.5 | 1.2 | 0.353 | 2.53 | 0.00440 |
| 2 | Gilberts | 3 | I/G | 7.3 | 7.8 | 18.1 | 7.37 | 0.0286 |
| 2 | Gilberts | 4 | I/G | 6.6 | 8.3 | 14.7 | 6.67 | 0.0304 |
| 2 | Highlands Elgin GC | 3 | Ancell | 4.1 | 3.7 | 5.77 | 4.14 | 0.0136 |
| 2 | South Elgin | 8 | Mt Simon | 1.6 | 4.3 | 0.129 | 1.62 | 0.0158 |
| 2 | South Elgin | 9 | Mt Simon | 2.1 | 4.8 | 0.130 | 2.12 | 0.0176 |
| 3 | Black Sheep GC | 1 | Ancell | 5.6 | 2.2 | 0.148 | 5.66 | 0.00807 |
| 3 | Montgomery | 14 | I/G | 4.7 | 6.0 | 0.126 | 4.75 | 0.0220 |
| 3 | Yorkville | 9 | I/G | 5.3 | 4.0 | 0.115 | 5.35 | 0.0147 |
| 4 | Channahon | 4 | I/G | 6.9 | 4.7 | 0.029 | 6.97 | 0.0172 |
| 4 | Exelon Fire Inst. | 2 | I/G | 0.6 | <1.0 | 0.020 | 0.61 | <0.00367 |
| 4 | Reichhold Chemical | 1 | Ancell | 2.2 | <0.9 | 0.011 | 2.22 | <0.00367 |
| 4 | Reichhold Chemical | 2 | Ancell | 6.2 | 4.1 | 0.022 | 6.26 | 0.0150 |
| 5 | Allstate | 6 | I/G | 4.8 | 6.0 | 0.047 | 4.85 | 0.0220 |
| 5 | Allstate | 5 | I/G | 4.2 | 6.2 | 0.029 | 4.24 | 0.0227 |
| 5 | Des Plaines MHP | 3 | Ancell | 2.3 | 1.9 | 0.017 | 2.32 | 0.00697 |
| 5 | Glen Club GC | 1 | Ancell | 3.8 | 2.5 | 0.017 | 3.84 | 0.00917 |
| 5 | Touhy MHP | 6 | I/G | 3.1 | 3.7 | 0.023 | 3.13 | 0.0136 |
| 5 | Wilmette GC | 4 | G/P | 9.5 | 1.8 | 0.014 | 9.60 | 0.00660 |
| 6 | Lake Villa | 14 | Ancell | 4.2 | 2.0 | 0.046 | 4.24 | 0.00734 |
| 6 | Scott Byron & Co. | 1 | G/P | 5.7 | 4.1 | 0.019 | 5.76 | 0.0150 |
| 6 | Thunder Hawk GC | 1 | I/G | 5.3 | 5.9 | 0.034 | 5.35 | 0.0216 |
| 6 | Volo | 5 | Mt Simon | 8.0 | 14.2 | 5.73 | 8.08 | 0.0521 |

CC = country club
GC = golf club
MHP = mobile home park
G/P = Galena/Platteville
I/G = Ironton/Galesville

than in the other groups, but the two Ironton/Galesville wells (Exelon 2 and Channahon 4) were deeper than most wells in other groups.

Conditions were reducing throughout the study area. ORP values varied between -94 and 211 millivolts (mV), with a median value of 94 mV. Nitrate was below detection in all samples (0.07 mg N/L), while ammonium-nitrogen ($NH_4$-N) concentrations varied between 0.16 and 0.98 mg/L, with a median value of 0.45 mg/L. Dissolved manganese (Mn) was detected in all but two samples (DL = 0.0015 mg/L). Concentrations were generally low, with a maximum value of 0.092 mg/L and a median of 0.009 mg/L. Dissolved iron (Fe) was also detected in all samples (median = 0.33 mg/L). Four samples had Fe concentrations greater than 1 mg/L; the two highest values (3.7 and 6.4 mg/L) were found in Ironton/Galesville wells (Touhy MHP 6 and Exelon Fire Inst. 2, respectively). Of the 20 wells from which gas samples were collected, 10 had detectable $CH_4$. Six wells had $CH_4$ concentrations > $10^{-5}$ mol/L (Clesen Brothers W and N, Elgin CC 5, Gilberts 3 and

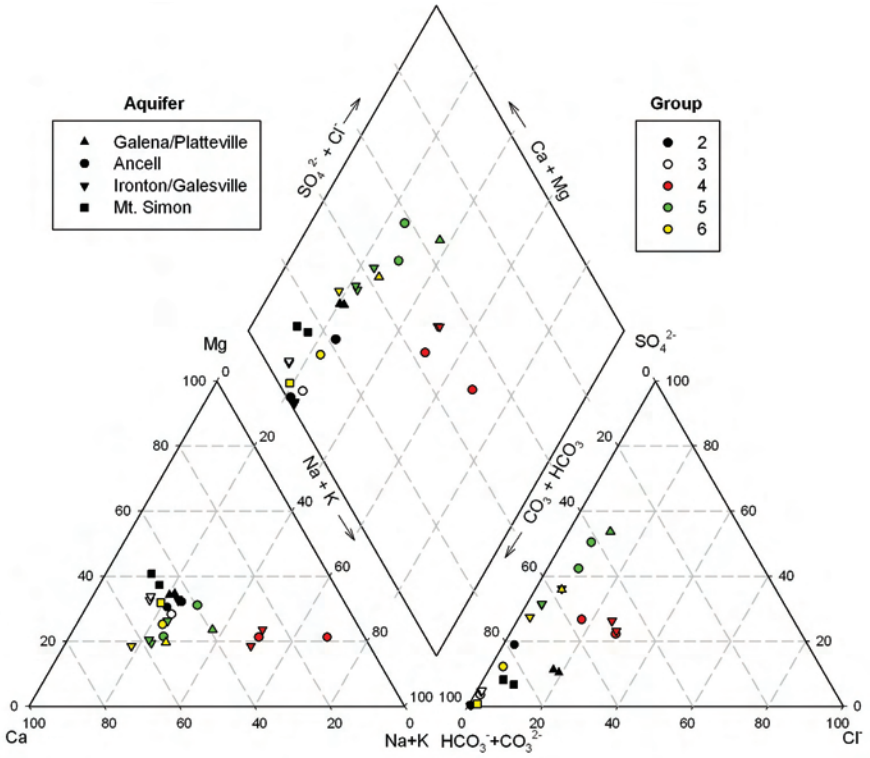


Figure 9. Piper diagram. Samples identified by aquifer (symbol shape) and group (color).

4, and Highlands of Elgin GC 3). All of these wells were in group 2. The presence of $CH_4$ indicates extremely reducing conditions.

Sulfide was detected (> 0.1 mg/L) at 11 of 23 wells (analyses were not conducted at the two Allstate wells), including five of the eight wells in group 2; three of the four wells in group 5; and two of the four wells in group 4. None of the Galena/Platteville wells had detectable $H_2S$ levels. Sulfide was above the upper detection limit (10 mg/L) in Highlands of Elgin GC 3 and > 1 mg/L in Des Plaines MHP 3 and Gilberts 3.

We would generally not expect to find significant concentrations of $SO_4^{2-}$ in samples where $H_2S$ is present, but 7 of the 10 wells with detectable $H_2S$ had $SO_4^{2-}$ concentrations > 10 mg/L and four had concentrations > 100 mg/L. All wells sampled in this study were high-capacity wells with long open intervals, drawing water into wellbores from large areas, potentially allowing for mixing of waters with significantly different chemistries. Sulfate concentrations were generally lowest in group 2 wells, especially if the two Galena/Platteville wells are not considered. Group 3 wells also had relatively low $SO_4^{2-}$ concentrations (all < 15 mg/L), while group 5 wells had the highest $SO_4^{2-}$ concentrations (all > 115 mg/L).

Total Ra and $^{226}Ra$ concentrations were plotted versus various chemical species and parameters in Figures 10 and 11. There were no obvious relationships observed for total Ra, although there was a weak positive correlation between $^{226}Ra$ and Sr ($r^2 = 0.17$) and a relationship between $^{226}Ra$ and Fe, i.e., elevated $^{226}Ra$ concentrations were generally only found when Fe concentrations were low and vice versa. TDS has been linked to elevated Ra concentrations, but this relationship was not observed for these samples (SpC is a proxy for TDS). This might be

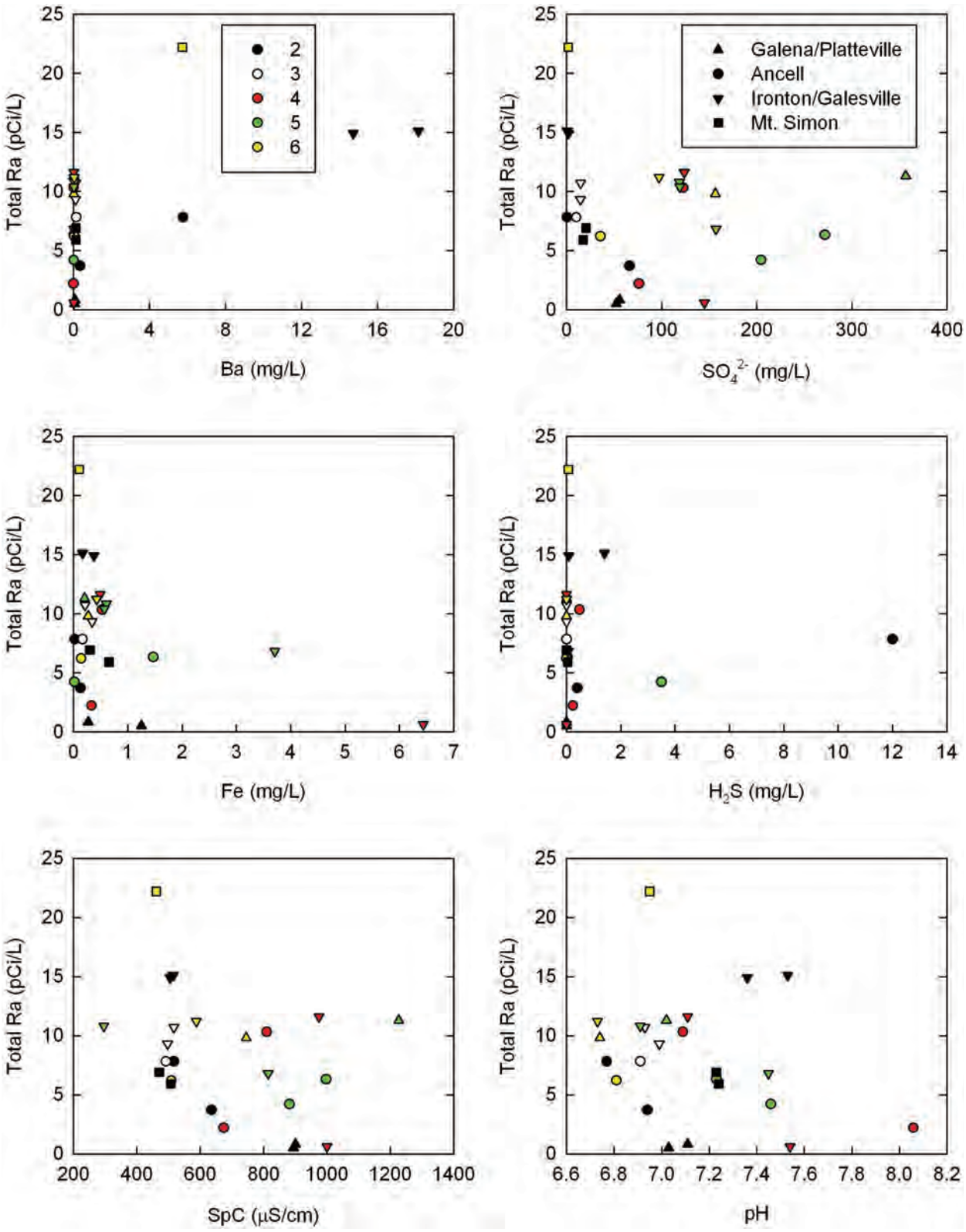


Figure 10. Total Ra ($^{226}Ra$ + $^{228}Ra$) vs. various chemical parameters. Samples identified by source aquifer (symbol shape) and group (color).

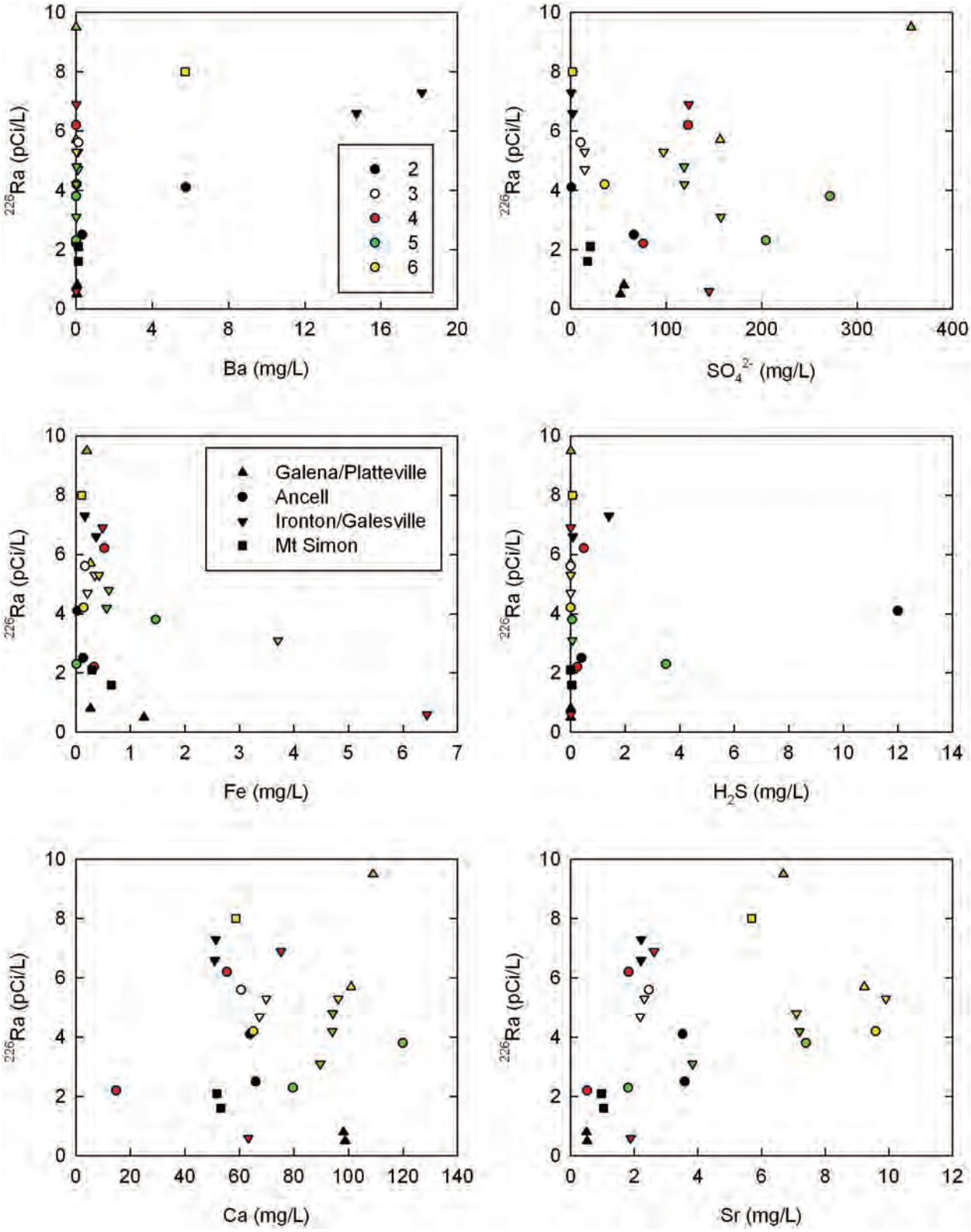


Figure 11. $^{226}$Ra vs. various chemical parameters.
Samples identified by source aquifer (symbol shape) and group (color).

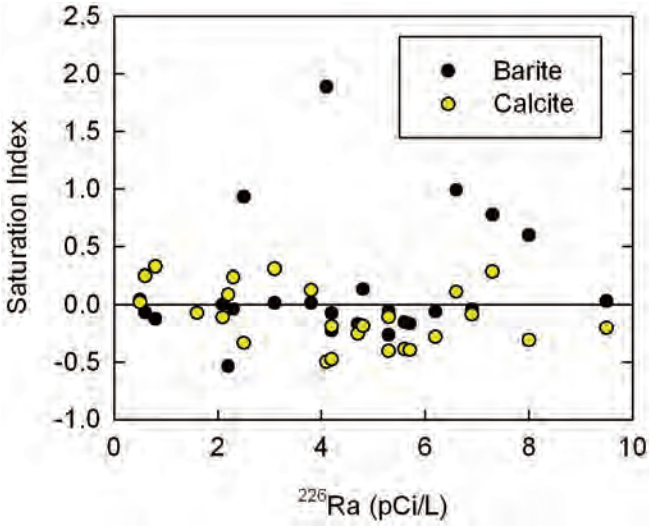


Figure 12. Barite and calcite saturation indices plotted vs. $^{226}$Ra.
When the saturation index = 0.0, the solution is saturated with respect to the mineral.

because most waters were relatively dilute; only one sample had a calculated TDS greater than 1000 mg/L (Wilmette GC 4). This well was the Galena/Platteville well with the highest total Ra. Most samples were at or near saturation with respect to barite and calcite, regardless of total Ra concentration (Figure 12). All samples were undersaturated with respect to gypsum.

Barium concentrations are plotted versus various chemical species and parameters in Figure 13. Barium concentrations are related to redox-sensitive species, particularly $SO_4^{2-}$ and Fe. Samples with elevated Ba concentrations had low concentrations of $SO_4^{2-}$ and Fe, while samples with relatively elevated $SO_4^{2-}$ or Fe had low Ba concentrations. Barium concentrations appear to be controlled by barite solubility, as Gilkeson et al. (1983) concluded. Most samples were at or near saturation with respect to barite. Samples that had elevated Ba had low concentrations of $SO_4^{2-}$, Fe, and $H_2S$ and were supersaturated with respect to barite (Figure 14). These were primarily wells in group 2. When $SO_4^{2-}$ is present, barite will precipitate; when it is not, Ba can accumulate in solution. The absence of $SO_4^{2-}$ and presence of $H_2S$ indicate $SO_4^{2-}$ reduction was occurring in these samples.

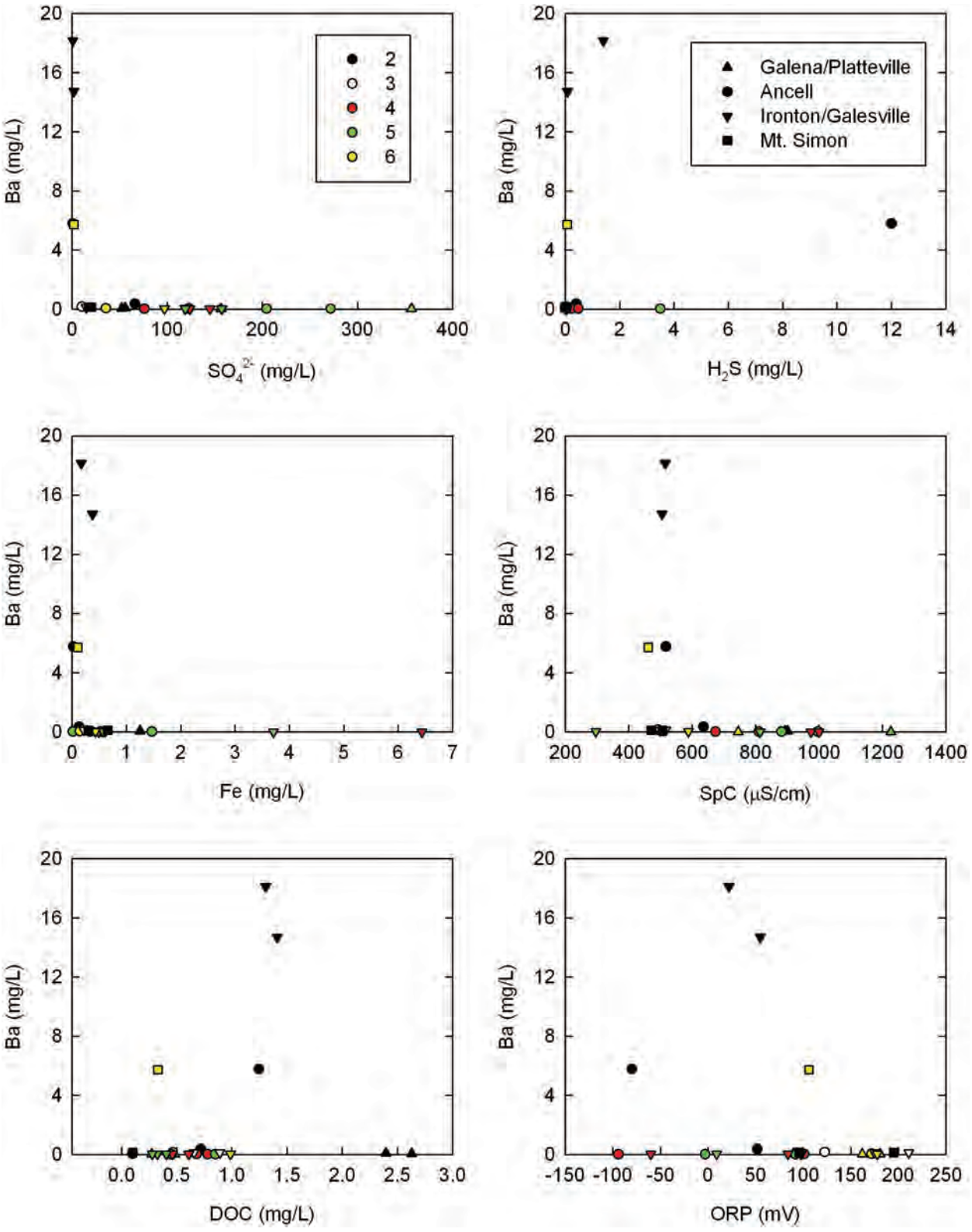


Figure 13. Dissolved Ba vs. various chemical parameters.
Samples identified by source aquifer (symbol shape) and group (color).

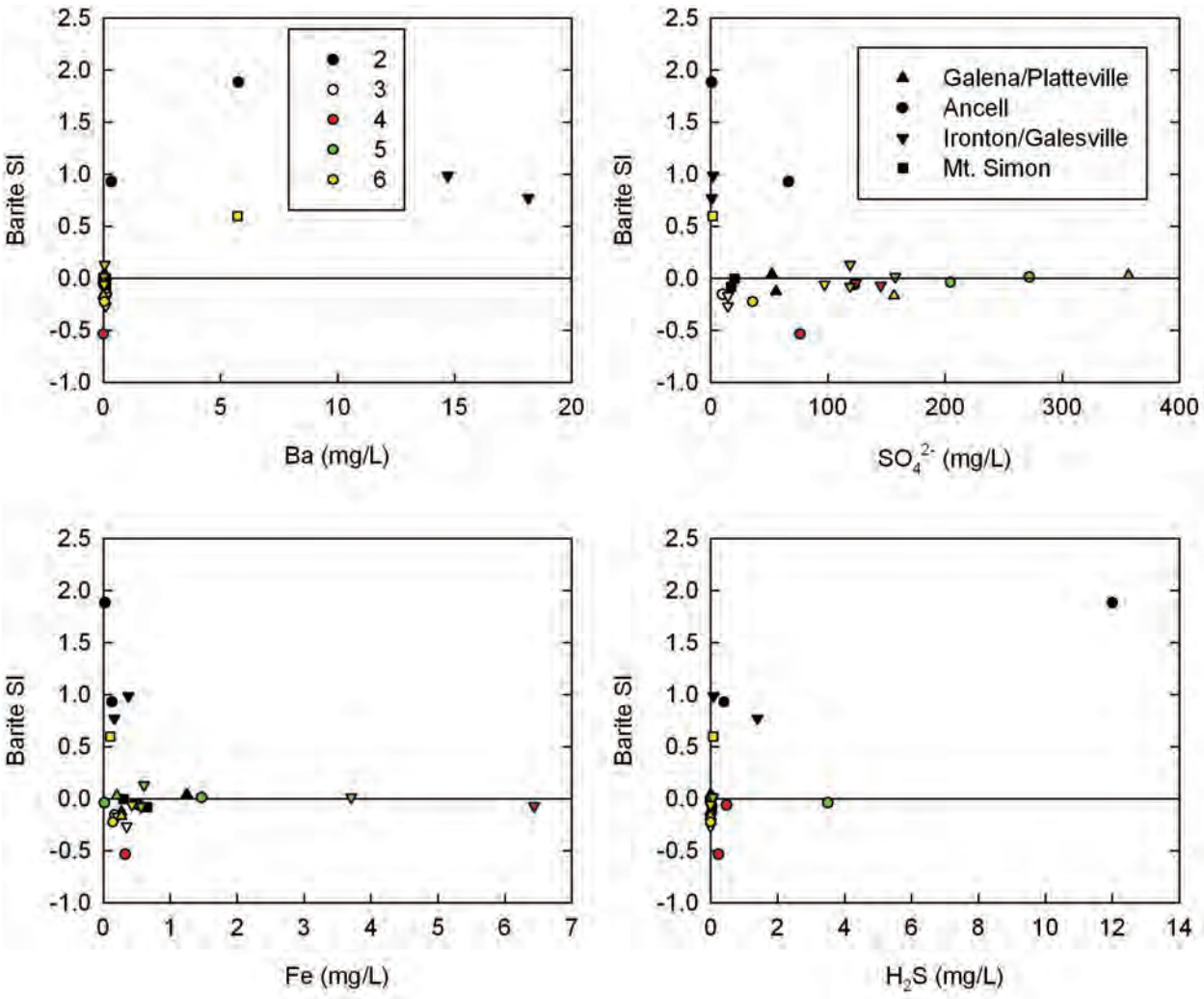


Figure 14. Barite saturation indices plotted vs. various chemical species.
Samples identified by source aquifer (symbol shape) and group (color).
When the saturation index = 0.0, the solution is saturated with respect to barite.

## Conclusions

The geographic distributions of Ra and Ba were consistent with results reported in other studies, including Gilkeson et al. (1983). Looking at the data as a whole, Ra and Ba concentrations did not significantly differ among the various deep bedrock aquifers. However, within the geographic groups there is some evidence that the Ironton/Galesville aquifer had higher Ra concentrations than the Galena/Platteville and Ancell aquifers. Also, Ba concentrations in group 2 were highest, by far, in the two Ironton/Galesville wells.

The MCL for Ra was exceeded in wells from all aquifers and the MCL for Ba was exceeded in wells from all the aquifers except the Galena/Platteville. Differences in $^{226}Ra/^{228}Ra$ ratios as a function of aquifer identity suggested there may be some differences in the source and mechanism of release of Ra into solution. The smaller percentage of $^{226}Ra$ in the Ironton/Galesville and Mt. Simon aquifers compared to the shallower aquifers may indicate less U in the deeper aquifer materials and/or that a significant fraction of the $^{226}Ra$ that has been produced has been transported away.

Barite appeared to be the primary control of both Ra and Ba concentrations, as both Gilkeson et al. (1983) and Grundl and Cape (2006) concluded. In areas where $SO_4^{2-}$ reduction has removed $SO_4^{2-}$ from solution (i.e., group 2), Ba can accumulate in solution. This in turn disables a mechanism for Ra removal (i.e., co-precipitation in barite). Three of the wells with Ba concentrations above the MCL (Gilberts 3 and 4 and Volo 5) had the three greatest Ra activities.

It appears that geographic location exerts a stronger control on overall groundwater chemistry, specifically Ra and Ba, than does the identity of the particular deep bedrock aquifer. Gilkeson et al. (1983) indicated that Ra and Ba concentrations are lowest in the location west of our study area where the Maquoketa Formation is absent, groundwater is relatively young and dilute, and conditions are not strongly reducing. When conditions become $SO_4^{2-}$ reducing down-gradient of this area, Ra and Ba can accumulate in solution. Further down-gradient where $SO_4^{2-}$ is re-introduced into solution, Ra and Ba concentrations decrease. Even further down-gradient, when waters become highly mineralized, Gilkeson et al. (1983) found the most elevated Ra concentrations in the region. Even though the presence of aquitards between the various aquifers should prevent mixing between the aquifers, it appears that each aquifer (at least from the Ancell and deeper) is following similar geochemical evolutionary pathways with similar effects on Ra and Ba chemistry. An additional factor to consider is that there are a large number of wells penetrating through all the deep bedrock aquifers in this region, which may allow for enhanced leakage between the aquifers. This may have the effect of reducing geochemical differences among aquifers.

This was a fairly small study, sampling 25 wells in five counties. Additional studies that could improve understanding of Ra and Ba occurrence in deep bedrock aquifers in northern Illinois include (1) expanding the study area and sampling of wells open to single units, including private domestic wells; (2) age dating of archived samples; and (3) analysis of cores collected and stored by the ISGS, including extractions, to determine where Ra resides.

## Acknowledgments

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| Group | County | Well Owner | Well # | Depth (ft) | Aquifer | ISWS p number | Twn Rng Sect | Date | T C | SpC µS/cm | pH | ORP mV | DO mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Kane | Elgin CC | 5 | 800 | Ancell | 411335 | 41N08E17 | 7/12/2007 | 13.7 | 636 | 6.94 | 52 | 0.9 |
| 2 | Kane | Highlands of Elgin GC | 3 | 902 | Ancell | 411556 | 41N08E22 | 7/12/2007 | 13.0 | 517 | 6.77 | -80 | 0.4 |
| 2 | Kane | South Elgin | 9 | 1958 | Mt. Simon | 400065 | 40N08E05 | 7/12/2007 | 17.2 | 471 | 7.23 | 195 | 0.5 |
| 2 | Kane | South Elgin | 8 | 1980 | Mt. Simon | 400064 | 40N08E05 | 7/12/2007 | 17.3 | 507 | 7.24 | 96 | 0.8 |
| 2 | Kane | Gilberts | 4 | 1330 | I/G | 400070 | 42N07E25 | 7/12/2007 | 15.8 | 505 | 7.36 | 55 | 3.0 |
| 2 | Kane | Gilberts | 3 | 1330 | I/G | 400071 | 42N07E25 | 7/12/2007 | 14.4 | 515 | 7.53 | 22 | 3.2 |
| 2 | Kane | Clesen Brothers | W | 260 | G/P | 404559 | 41N08E35 | 7/12/2007 | 13.3 | 894 | 7.03 | 90 | 0.5 |
| 2 | Kane | Clesen Brothers | N | 375 | G/P | 401971 | 41N08E35 | 7/12/2007 | 28.1 | 900 | 7.11 | 93 | 0.3 |
| 3 | Kendall | Yorkville | 9 | 1368 | I/G | 411221 | 37N07E15 | 7/19/2007 | 18.9 | 497 | 6.99 | 175 | 1.2 |
| 3 | Kane | Black Sheep GC | 1 | 880 | Ancell | 412116 | 39N07E28 | 7/19/2007 | 12.5 | 492 | 6.91 | 123 | 0.5 |
| 3 | Kane | Montgomery | 14 | 1403 | I/G | 411012 | 38N07E35 | 7/19/2007 | 16.2 | 517 | 6.93 | 211 | 0.5 |
| 4 | Grundy | Reichhold Chemical | 1 | 706 | Ancell | 401655 | 34N08E34 | 7/19/2007 | 17.3 | 674 | 8.06 | -94 | 0.3 |
| 4 | Grundy | Reichhold Chemical | 2 | 710 | Ancell | 401657 | 34N08E34 | 7/19/2007 | 14.1 | 810 | 7.09 | 101 | 1.9 |
| 4 | Will | Channahon | 4 | 1647 | I/G | 410382 | 34N09E30 | 7/19/2007 | 17.6 | 975 | 7.11 | 84 | 0.9 |
| 4 | Grundy | Exelon Fire Institute | 2 | 1375 | I/G | 412026 | 33N07E08 | 7/30/2007 | 13.5 | 1000 | 7.54 | -60 | 0.5 |
| 5 | Cook | Wilmette GC | 4 | 798 | G/P | 404928 | 42N12E25 | 7/11/2007 | 13.8 | 1227 | 7.02 | 181 | 3.8 |
| 5 | Cook | Glen Club GC | 1 | 1400 | Ancell | 411269 | 42N12E27 | 7/11/2007 | 15.6 | 997 | 7.23 | 92 | 6.8 |
| 5 | Cook | Touhy MHP | 6 | 1295 | I/G | 405568 | 41N11E25 | 7/11/2007 | 14.7 | 814 | 7.45 | 9 | 1.2 |
| 5 | Cook | Des Plaines MHP | 3 | 960 | Ancell | 405051 | 41N11E25 | 7/11/2007 | 14.9 | 882 | 7.46 | -3 | 5.2 |
| 5 | Cook | Allstate | 6 | 1328 | I/G | 400848 | 42N12E19 | 7/30/2007 | 20.1 | 296 | 6.91 | 98 | 0.5 |
| 5 | Cook | Allstate | 5 | 1352 | I/G | 400847 | 42N12E19 | 7/30/2007 | | | | | |
| 6 | Lake | Volo | 5 | 1400 | Mt. Simon | 412003 | 44N09E02 | 7/30/2007 | 16.9 | 461 | 6.95 | 106 | 0.4 |
| 6 | Lake | Thunder Hawk GC | 1 | 1305 | I/G | 405559 | 46N12E29 | 7/31/2007 | 19.1 | 588 | 6.73 | 178 | 0.9 |
| 6 | Lake | Scott Byron & Co. | 1 | 1060 | G/P | 411365 | 46N11E25 | 7/31/2007 | 19.3 | 745 | 6.74 | 162 | 0.3 |
| 6 | Lake | Lake Villa | 14 | 1000 | Ancell | 412143 | 45N10E05 | 7/31/2007 | 16.4 | 509 | 6.81 | 172 | 0.5 |

CC = country club
GC = golf club
MHP = mobile home park

| Group | County | Well Owner | Well # | $H_2S$ mg/L | $^{226}Ra$ pCi/L | $^{228}Ra$ pCi/L | Tot Ra pCi/L | CH4 mol | Al mg/L | As µg/L | B mg/L | Ba mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Kane | Elgin CC | 5 | 0.4 | 2.5 | 1.2 | 3.7 | 4.74E-04 | 0.0157 | <2 | 0.370 | 0.353 | 66.0 |
| 2 | Kane | Highlands of Elgin GC | 3 | >10 | 4.1 | 3.7 | 7.8 | 1.72E-03 | 0.0138 | <2 | 0.192 | 5.77 | 63.9 |
| 2 | Kane | South Elgin | 9 | ND | 2.1 | 4.8 | 6.9 | ND | 0.0162 | <2 | 0.176 | 0.130 | 51.8 |
| 2 | Kane | South Elgin | 8 | 0.04 | 1.6 | 4.3 | 5.9 | ND | 0.0109 | <2 | 0.202 | 0.129 | 53.1 |
| 2 | Kane | Gilberts | 4 | 0.08 | 6.6 | 8.3 | 14.9 | 1.23E-03 | 0.0104 | <2 | 0.118 | 14.7 | 51.0 |
| 2 | Kane | Gilberts | 3 | 1.4 | 7.3 | 7.8 | 15.1 | 1.13E-03 | 0.0127 | <2 | 0.116 | 18.1 | 51.4 |
| 2 | Kane | Clesen Brothers | W | ND | 0.5 | <1.0 | 0.5 | 9.78E-05 | 0.0185 | <2 | 0.253 | 0.066 | 98.8 |
| 2 | Kane | Clesen Brothers | N | ND | 0.8 | <1.0 | 0.8 | 1.53E-04 | 0.0177 | <2 | 0.243 | 0.078 | 98.2 |
| 3 | Kendall | Yorkville | 9 | ND | 5.3 | 4.0 | 9.3 | ND | 0.0181 | <2 | 0.316 | 0.115 | 69.8 |
| 3 | Kane | Black Sheep GC | 1 | ND | 5.6 | 2.2 | 7.8 | 9.18E-07 | 0.0158 | <2 | 0.385 | 0.148 | 60.7 |
| 3 | Kane | Montgomery | 14 | ND | 4.7 | 6.0 | 10.7 | ND | 0.0145 | <2 | 0.288 | 0.126 | 67.4 |
| 4 | Grundy | Reichhold Chemical | 1 | 0.24 | 2.2 | <0.9 | 2.2 | 3.41E-06 | 0.0093 | <2 | 0.553 | 0.011 | 14.8 |
| 4 | Grundy | Reichhold Chemical | 2 | 0.48 | 6.2 | 4.1 | 10.3 | ND | 0.0121 | <2 | 0.649 | 0.022 | 55.5 |
| 4 | Will | Channahon | 4 | ND | 6.9 | 4.7 | 11.6 | ND | 0.0218 | <2 | 0.756 | 0.029 | 75.2 |
| 4 | Grundy | Exelon Fire Institute | 2 | ND | 0.6 | <1.0 | 0.6 | ND | 0.013 | <2 | 0.661 | 0.020 | 63.3 |
| 5 | Cook | Wilmette GC | 4 | ND | 9.5 | 1.8 | 11.3 | NA | 0.0211 | <2 | 0.693 | 0.014 | 109 |
| 5 | Cook | Glen Club GC | 1 | 0.05 | 3.8 | 2.5 | 6.3 | ND | 0.0228 | <2 | 0.456 | 0.017 | 120 |
| 5 | Cook | Touhy MHP | 6 | 0.06 | 3.1 | 3.7 | 6.8 | ND | 0.0173 | <2 | 0.325 | 0.023 | 89.6 |
| 5 | Cook | Des Plaines MHP | 3 | 3.5 | 2.3 | 1.9 | 4.2 | 5.67E-06 | 0.0207 | <2 | 0.314 | 0.017 | 79.7 |
| 5 | Cook | Allstate | 6 | NA | 4.8 | 6.0 | 10.8 | ND | 0.0227 | <2 | 0.314 | 0.047 | 94.3 |
| 5 | Cook | Allstate | 5 | NA | 4.2 | 6.2 | 10.4 | NA | 0.0364 | <2 | 0.298 | 0.029 | 94.1 |
| 6 | Lake | Volo | 5 | 0.07 | 8.0 | 14.2 | 22.2 | ND | 0.0135 | <2 | 0.141 | 5.73 | 58.7 |
| 6 | Lake | Thunder Hawk GC | 1 | ND | 5.3 | 5.9 | 11.2 | NA | 0.0184 | <2 | 0.219 | 0.034 | 96.2 |
| 6 | Lake | Scott Byron & Co. | 1 | ND | 5.7 | 4.1 | 9.8 | ND | 0.0208 | <2 | 0.329 | 0.019 | 101 |
| 6 | Lake | Lake Villa | 14 | ND | 4.2 | 2.0 | 6.2 | ND | 0.0158 | <2 | 0.191 | 0.046 | 65.1 |

ND = not detected
NA = not analyzed

| *Group* | *County* | *Well Owner* | *Well #* | *Cu mg/L* | *Fe mg/L* | *K mg/L* | *Li mg/L* | *Mg mg/L* | *Mn mg/L* | *Na mg/L* | *Ni mg/L* | *S mg/L* | *Si mg/L* | *Sr mg/L* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Kane | Elgin CC | 5 | 0.00082 | 0.133 | 13.5 | 0.0245 | 29.7 | 0.0124 | 35.1 | <0.014 | 23.5 | 3.38 | 3.59 |
| 2 | Kane | Highlands of Elgin GC | 3 | <0.00079 | 0.029 | 11.3 | 0.0138 | 24.6 | 0.0016 | 26.3 | <0.014 | 2.77 | 3.41 | 3.52 |
| 2 | Kane | South Elgin | 9 | <0.00079 | 0.298 | 10.7 | 0.0171 | 27.2 | 0.0136 | 9.2 | <0.014 | 7.34 | 3.85 | 0.96 |
| 2 | Kane | South Elgin | 8 | <0.00079 | 0.656 | 10.8 | 0.0198 | 25.7 | 0.0279 | 14.7 | <0.014 | 6.44 | 3.99 | 1.03 |
| 2 | Kane | Gilberts | 4 | <0.00079 | 0.374 | 8.52 | 0.0062 | 23.4 | 0.0050 | 26.1 | 0.041 | 0.936 | 3.58 | 2.21 |
| 2 | Kane | Gilberts | 3 | 0.00124 | 0.166 | 8.72 | 0.0067 | 22.9 | 0.0041 | 26.2 | <0.014 | 0.619 | 3.55 | 2.22 |
| 2 | Kane | Clesen Brothers | W | <0.00079 | 1.25 | 6.81 | 0.0105 | 47.1 | 0.0219 | 51.3 | 0.022 | 19.2 | 6.78 | 0.52 |
| 2 | Kane | Clesen Brothers | N | <0.00079 | 0.271 | 6.77 | 0.0093 | 44.7 | 0.0343 | 46.2 | 0.021 | 19.5 | 6.66 | 0.49 |
| 3 | Kendall | Yorkville | 9 | <0.00079 | 0.347 | 14.1 | 0.0194 | 26.8 | 0.0034 | 16.3 | <0.014 | 5.35 | 3.63 | 2.31 |
| 3 | Kane | Black Sheep GC | 1 | <0.00079 | 0.170 | 13.8 | 0.0348 | 21.7 | 0.0030 | 26.4 | <0.014 | 3.74 | 3.40 | 2.47 |
| 3 | Kane | Montgomery | 14 | 0.02265 | 0.213 | 13.2 | 0.0201 | 27.3 | 0.0025 | 15.8 | <0.014 | 5.42 | 3.71 | 2.19 |
| 4 | Grundy | Reichhold Chemical | 1 | <0.00079 | 0.334 | 17.1 | 0.0510 | 18.9 | 0.0104 | 106 | <0.014 | 27.2 | 0.67 | 0.52 |
| 4 | Grundy | Reichhold Chemical | 2 | <0.00079 | 0.528 | 16.9 | 0.0544 | 25.3 | 0.0076 | 104 | <0.014 | 41.4 | 3.59 | 1.83 |
| 4 | Will | Channahon | 4 | <0.00079 | 0.491 | 17.9 | 0.0614 | 26.8 | 0.0119 | 125 | <0.014 | 46.3 | 3.86 | 2.62 |
| 4 | Grundy | Exelon Fire Institute | 2 | 0.00086 | 6.438 | 18.9 | 0.0686 | 34.7 | 0.0583 | 129 | 0.014 | 50.1 | 3.60 | 1.89 |
| 5 | Cook | Wilmette GC | 4 | 0.00098 | 0.205 | 19.8 | 0.0499 | 39.5 | 0.0047 | 106 | <0.014 | 120 | 3.85 | 6.69 |
| 5 | Cook | Glen Club GC | 1 | <0.00079 | 1.47 | 16.5 | 0.0380 | 29.1 | 0.0299 | 55.0 | <0.014 | 89.7 | 3.83 | 7.39 |
| 5 | Cook | Touhy MHP | 6 | <0.00079 | 3.71 | 12.5 | 0.0309 | 28.5 | 0.0921 | 41.4 | <0.014 | 52.8 | 3.64 | 3.83 |
| 5 | Cook | Des Plaines MHP | 3 | <0.00079 | 0.019 | 8.71 | 0.0321 | 37.9 | <0.0015 | 62.5 | 0.016 | 67.6 | 3.62 | 1.81 |
| 5 | Cook | Allstate | 6 | 0.0051 | 0.609 | 13.9 | 0.0238 | 19.3 | 0.0219 | 34.5 | <0.014 | 40.9 | 3.76 | 7.09 |
| 5 | Cook | Allstate | 5 | <0.00079 | 0.565 | 13.5 | 0.0230 | 20.2 | 0.0167 | 32.6 | <0.014 | 41.0 | 3.71 | 7.20 |
| 6 | Lake | Volo | 5 | <0.00079 | 0.106 | 10.1 | 0.0122 | 23.2 | <0.0015 | 20.3 | 0.018 | 0.762 | 4.00 | 5.69 |
| 6 | Lake | Thunder Hawk GC | 1 | <0.00079 | 0.427 | 11.5 | 0.0145 | 17.0 | 0.0090 | 24.6 | <0.014 | 34.2 | 3.90 | 9.90 |
| 6 | Lake | Scott Byron & Co. | 1 | <0.00079 | 0.272 | 13.3 | 0.0226 | 22.6 | 0.0090 | 49.4 | <0.014 | 54.6 | 4.02 | 9.23 |
| 6 | Lake | Lake Villa | 14 | <0.00079 | 0.143 | 10.5 | 0.0160 | 19.2 | 0.0033 | 26.9 | <0.014 | 12.9 | 3.88 | 9.58 |

| Group | County | Well Owner | Well # | Tl mg/L | Zn mg/L | Lab pH | Alkalinity mg/L | $F^-$ mg/L | $Cl^-$ mg/L | $NO_3$-N mg/L | $SO_4^{2-}$ mg/L | DOC mg/L | $NH_3$-N mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Kane | Elgin CC | 5 | <0.017 | <0.0073 | 7.58 | 286 | 0.81 | 7.89 | <0.07 | 66.4 | 0.718 | 0.698 |
| 2 | Kane | Highlands of Elgin GC | 3 | <0.017 | <0.0073 | 7.80 | 324 | 0.64 | 1.77 | <0.07 | 0.85 | 1.24 | 0.454 |
| 2 | Kane | South Elgin | 9 | <0.017 | <0.0073 | 7.68 | 225 | 0.78 | 10.1 | <0.07 | 20.5 | <0.21 | 0.295 |
| 2 | Kane | South Elgin | 8 | <0.017 | <0.0073 | 7.78 | 233 | 0.84 | 17.7 | <0.07 | 17.5 | <0.21 | 0.286 |
| 2 | Kane | Gilberts | 4 | <0.017 | <0.0073 | 7.87 | 288 | 0.49 | 1.61 | <0.07 | 1.82 | 1.41 | 0.435 |
| 2 | Kane | Gilberts | 3 | <0.017 | 0.012 | 8.04 | 293 | 0.46 | 1.49 | <0.07 | 0.79 | 1.31 | 0.436 |
| 2 | Kane | Clesen Brothers | W | <0.017 | 0.038 | 7.74 | 373 | 0.34 | 71.6 | <0.07 | 52.3 | 2.63 | 0.432 |
| 2 | Kane | Clesen Brothers | N | <0.017 | 0.019 | 7.73 | 370 | 0.30 | 63.3 | <0.07 | 56.0 | 2.40 | 0.336 |
| 3 | Kendall | Yorkville | 9 | <0.017 | <0.0073 | 7.52 | 311 | 0.75 | 2.94 | <0.07 | 14.6 | 0.890 | 0.565 |
| 3 | Kane | Black Sheep GC | 1 | <0.017 | <0.0073 | 7.54 | 288 | 1.01 | 3.64 | <0.07 | 10.3 | 0.464 | 0.625 |
| 3 | Kane | Montgomery | 14 | <0.017 | 0.008 | 7.55 | 299 | 0.73 | 3.22 | <0.07 | 14.7 | 0.656 | 0.533 |
| 4 | Grundy | Reichhold Chemical | 1 | <0.017 | <0.0073 | 8.46 | 178 | 0.73 | 72.1 | <0.07 | 76.2 | 0.781 | 0.556 |
| 4 | Grundy | Reichhold Chemical | 2 | <0.017 | 0.022 | 7.67 | 270 | 0.89 | 58.1 | <0.07 | 123 | 0.679 | 0.778 |
| 4 | Will | Channahon | 4 | 0.02 | 0.008 | 7.63 | 273 | 1.09 | 111 | <0.07 | 124 | 0.608 | 0.794 |
| 4 | Grundy | Exelon Fire Institute | 2 | <0.017 | 0.009 | 7.80 | 278 | 0.62 | 103 | <0.07 | 145 | 0.460 | 0.981 |
| 5 | Cook | Wilmette GC | 4 | <0.017 | 0.013 | 7.56 | 243 | 1.26 | 54.6 | <0.07 | 357 | 0.479 | 0.596 |
| 5 | Cook | Glen Club GC | 1 | <0.017 | <0.0073 | 7.58 | 235 | 1.21 | 30.7 | <0.07 | 272 | 0.451 | 0.509 |
| 5 | Cook | Touhy MHP | 6 | <0.017 | <0.0073 | 7.71 | 257 | 0.85 | 22.5 | <0.07 | 157 | 0.407 | 0.450 |
| 5 | Cook | Des Plaines MHP | 3 | <0.017 | <0.0073 | 7.74 | 248 | 0.31 | 29.8 | <0.07 | 205 | 0.850 | 0.852 |
| 5 | Cook | Allstate | 6 | <0.017 | 0.054 | 7.71 | 256 | 1.10 | 11.6 | <0.07 | 119 | 0.323 | 0.361 |
| 5 | Cook | Allstate | 5 | <0.017 | <0.0073 | 7.60 | 254 | 1.10 | 11.3 | <0.07 | 119 | 0.279 | 0.348 |
| 6 | Lake | Volo | 5 | <0.017 | 0.012 | 7.62 | 271 | 0.71 | 4.48 | <0.07 | 1.90 | 0.329 | 0.302 |
| 6 | Lake | Thunder Hawk GC | 1 | 0.02 | 0.014 | 7.39 | 258 | 1.34 | 7.51 | <0.07 | 97.3 | 0.987 | 0.156 |
| 6 | Lake | Scott Byron & Co. | 1 | 0.02 | 0.025 | 7.47 | 259 | 1.48 | 23.0 | <0.07 | 157 | 0.273 | 0.245 |
| 6 | Lake | Lake Villa | 14 | <0.017 | 0.010 | 7.61 | 259 | 1.06 | 7.39 | <0.07 | 35.8 | <0.21 | 0.229 |